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By George R. Kinney and Richard O. Niemi

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

WASHINGTON

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NACA AIRCRAFT ENGINE RESEARCH LABORATORY

MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

THE EFFECT OF ETHYLENE DIBROMIDE ON THE KNOCK-LIMITED PERFORMANCE OF LEADED AND NONLEADED S REFERENCE FUEL

By George R. Kinney and Richard O. Niemi

INTRODUCTION

Previous investigations of lead fouling have indicated that some advantages may result if the concentration of ethylene dibromide in aviation fuel is increased above the 1-T concentration currently used. (1-T or 1 theory of ethylene dibromide is the chemically correct amount required to combine with the tetraethyl lead in a fuel to convert all the lead to lead bromide.) The use of fuel with the ethylene-dibromide content increased from 1 theory to 1.5 theories has resulted in decreased lead fouling of the spark plugs in aircraft engines. The results of tests reported in reference 1 show that, when ethylene dibromide in excess of the amount theoretically required to combine with the lead in the fuel was added, hot corrosion of the exhaust-valve crown and material deposits on the piston and the spark plugs were reduced.

Tests with an air-cooled, single-cylinder engine (reference 1) showed no reduction in the knock-limited power of an AN-F-28, Amendment-2, fuel when the ethylene-dibromide concentration was increased from 1 theory to 2 theories; however, during tests performed at the NACA Cleveland laboratory on lead fouling of spark plugs, the knock-limited power of a CFR engine decreased when ethylene dibromide was added to nonleaded S reference fuel.

These observations suggested the possibility that the effect of ethylene dibromide on the knock-limited power of an engine might depend upon the concentration of tetraethyl lead in the fuel. Tests

were therefore conducted on a CFR (F-4) engine to determine the effect of ethylene dibromide on the knock-limited performance of S reference fuel, both nonleaded and leaded to 6 ml TEL per gallon. The tests reported herein were made at the NACA Cleveland laboratory during October 1944 as part of an investigation of lead fouling of spark plugs requested by the Air Technical Service Command, Army Air Forces.

APPARATUS AND TESTS

The knock tests were conducted with a modified F-4 engine. The modifications involved only details of some of the engine auxiliary systems.

Air consumption was measured by a calibrated orifice, fuel consumption was determined by an automatic time-weight method, and temperatures were measured by chromel-alumel thermocouples. An alternating-current, induction-type dynamometer was used to measure torque. Knock was detected by a magnetostriction-type pickup unit (attached to the cylinder) in combination with an amplifier and a cathode-ray oscilloscope. The knock intensity selected to establish the knock limits of the fuels was the intensity that caused the first perceptible indication on the oscilloscope; this intensity was below that for audible knock.

The knock tests were performed with the following F-4 operating conditions maintained:

Engine speed, rpm	1800 ±45
Compression ratio	7.0
Spark advance, degrees B.T.C.	45 ±1
Spark-plug gap, inches	0.015 to 0.025
Coolant temperature, °F	375 ±5
Inlet-air temperature, °F	225 ±5
Lubricating-oil temperature, °F	165 ±5

The humidity of the inlet air was not in excess of 70 grains of water per pound of dry air.

Knock-limited indicated mean effective pressure was determined over a range of fuel-air ratios for S reference fuel containing 6 ml TEL per gallon with the following concentrations of ethylene dibromide in milliliters per gallon: 0, 2.67 (1-T), 4.01 (1.5-T), and 5.34 (2-T). Similar tests were also run using S reference fuel containing no tetraethyl lead and with ethylene-dibromide concentrations of 0, 2.67, and 5.34 milliliters per gallon. Comparisons of

knock-limited performance were made only among fuels tested on the same day. Corresponding bracketing standard reference-fuel curves were run for the knock-test data obtained on each day.

RESULTS AND DISCUSSION

Knock-limited performance data obtained under F-4 operating conditions for leaded and nonleaded S reference fuel containing different concentrations of ethylene dibromide are presented in figures 1, 2, and 3 and table I summarizes the knock-limited performance data presented in these figures. The table gives, at several fuel-air ratios, the relative knock-limited powers of the leaded fuel with the different amounts of ethylene dibromide with respect to the knock-limited power of the leaded fuel containing 1 theory of ethylene dibromide. The table also gives the relative knock-limited powers of the nonleaded fuel with the different amounts of ethylene dibromide with respect to the knock-limited power of the nonleaded fuel containing no ethylene dibromide.

Figure 1(a) shows that no appreciable difference in the knock-limited power of S reference fuel containing 6 ml TEL per gallon was found when the ethylene-dibromide content was decreased from 1 theory to 0 theory; nor was there any appreciable difference (see fig. 1(b)) when the ethylene-dibromide content was increased from 1 theory to 1.5 theories. A decrease in knock-limited power, shown in figure 1(c), of approximately 8 percent at lean fuel-air mixtures and 6 percent at rich fuel-air mixtures occurred, however, when the ethylene dibromide was increased from 1 theory to 2 theories.

The knock-limited performance data showing the effect of additions of 2.67 and 5.34 milliliters of ethylene dibromide per gallon (amounts equivalent to 1 and 2 theories, respectively, for a tetraethyl lead content of 6 ml/gal) to the nonleaded fuel are presented in figure 2. The knock-limited performance of nonleaded S reference fuel was reduced by the additions of ethylene dibromide except at very lean and very rich fuel-air mixtures where little change was detected. The reduction in the knock-limited performance of the fuel was greater with the larger addition of ethylene dibromide. Changes in the knock-limited power of the nonleaded fuel for differences of 2.67 milliliters per gallon in ethylene-dibromide content were relatively small but were reproducible.

Figure 3 presents knock-limited performance data obtained in check tests; the data check the results shown in figures 1 and 2.

An increase in the ethylene-dibromide content from 0 to 5.34 milliliters per gallon decreased the knock-limited power of both the leaded and the nonleaded fuel approximately the same amount (6 to 9 percent depending upon the fuel-air ratio) except at very lean and very rich fuel-air mixtures where little change in the knock-limited power of the nonleaded fuel was detected. An increase in the ethylene-dibromide content from 0 to 2.67 milliliters per gallon decreased the knock-limited power of the nonleaded fuel as high as 6 percent depending upon the fuel-air ratio (except at very lean and very rich fuel-air mixtures where little change in knock-limited power was detected) but had no appreciable effect on the knock-limited power of the leaded fuel. An increase from 0 to 4.01 milliliters per gallon of ethylene dibromide also had no appreciable effect on the knock-limited power of the leaded fuel.

SUMMARY OF RESULTS

The results of tests made with a modified F-4 engine using F-4 operating conditions to determine the effect of ethylene dibromide on the knock-limited performance of leaded and nonleaded S reference fuel are summarized below. The tests were made with slight deviations from the strict F-4 instrumentation and knock-rating procedure. The knock intensity selected to establish the knock limits of the fuels was determined by an oscilloscope method and was below that for audible knock.

1. An increase in the ethylene-dibromide content from 0 to 5.34 milliliters per gallon (0-T to 2-T for 6 ml TEL/gal) decreased the knock-limited power of S reference fuel, both nonleaded and leaded to 6 ml TEL per gallon, approximately the same amount (6 to 9 percent depending upon the fuel-air ratio) except at very lean and very rich fuel-air mixtures where little change in the knock-limited power of the nonleaded fuel was detected.

2. An increase in the ethylene-dibromide content from 0 to 2.67 milliliters per gallon (0-T to 1-T for 6 ml TEL/gal) decreased the knock-limited power of the nonleaded S reference fuel as much as 6 percent depending upon the fuel-air ratio (except at very lean and very rich fuel-air mixtures where little change in the knock-limited power was detected) but had no appreciable effect on the knock-limited power of S reference fuel leaded to 6 ml TEL per gallon.

3. An increase from 0 to 4.01 milliliters per gallon of ethylene dibromide (0-T to 1.5-T for 6 ml TEL/gal) had no appreciable effect on the knock-limited power of S reference fuel leaded to 6 ml TEL per gallon.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCE

1. Mulcahy, B. A., and Zipkin, M. A.: The Effects of an Increase in the Concentration of Ethylene Dibromide in a Leaded Fuel on Lead Deposition, Corrosion of Exhaust Valves, and Knock-Limited Power. NACA ARR No. E5E04a, 1945.

TABLE I - SUMMARY OF THE EFFECT OF ETHYLENE DIBROMIDE IN LEADED AND NONLEADED S REFERENCE FUEL ON THE KNOCK-LIMITED POWER OF A CFR ENGINE UNDER F-4 OPERATING CONDITIONS

[Where two values are given in the table for the same determination, the second value was obtained from a check run]

Leaded S reference fuel				
Ethylene dibromide in S reference fuel + 6 ml TEL (ml/gal)	Relative power[a]			
	Fuel-air ratio			
	0.062	0.070	0.090	0.110
2.67 (1-T)	1.00	1.00	1.00	1.00
0 (0-T)	0.98	1.00	1.01 1.01	1.00
4.01 (1.5-T)	1.01 .99	1.01 1.00	1.01 .98	1.01 1.00
5.34 (2-T)	0.92	0.91	0.94 .95	0.95 .93
Nonleaded S reference fuel				
Ethylene dibromide in nonleaded S reference fuel (ml/gal)	Relative power[b]			
	Fuel-air ratio			
	0.062	0.070	0.090	0.110
0	1.00	1.00	1.00	1.00
2.67	0.98	0.96	0.94 .96	0.97 .98
5.34	0.97	0.92	0.92 .94	0.97 .96

[a] $\frac{\text{imep (S + 6 ml TEL + test concentration of ethylene dibromide)}}{\text{imep (S + 6 ml TEL + 2.67 ml ethylene dibromide (1-T))}}$.

[b] $\frac{\text{imep (S + test concentration of ethylene dibromide)}}{\text{imep (S)}}$.

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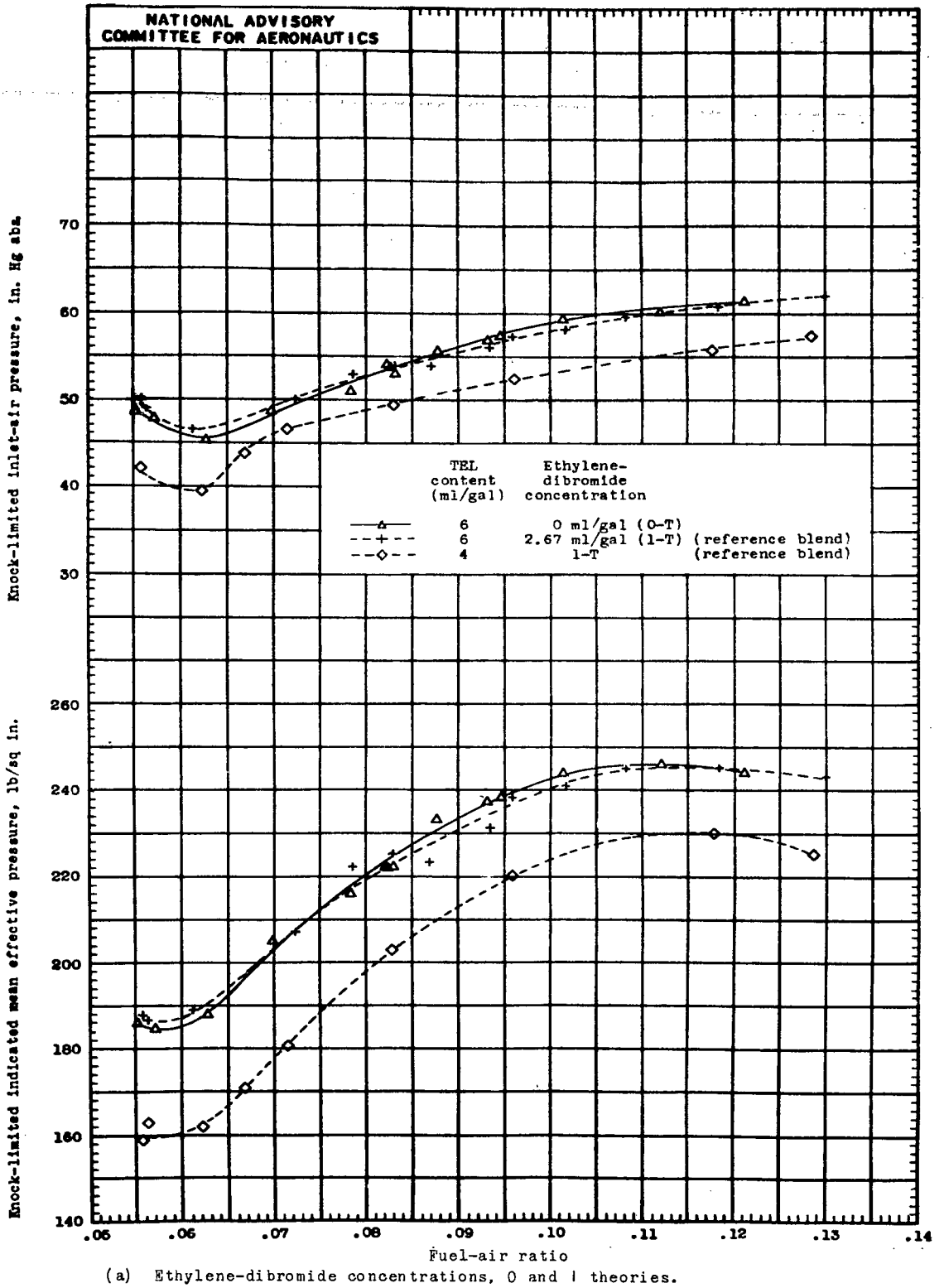
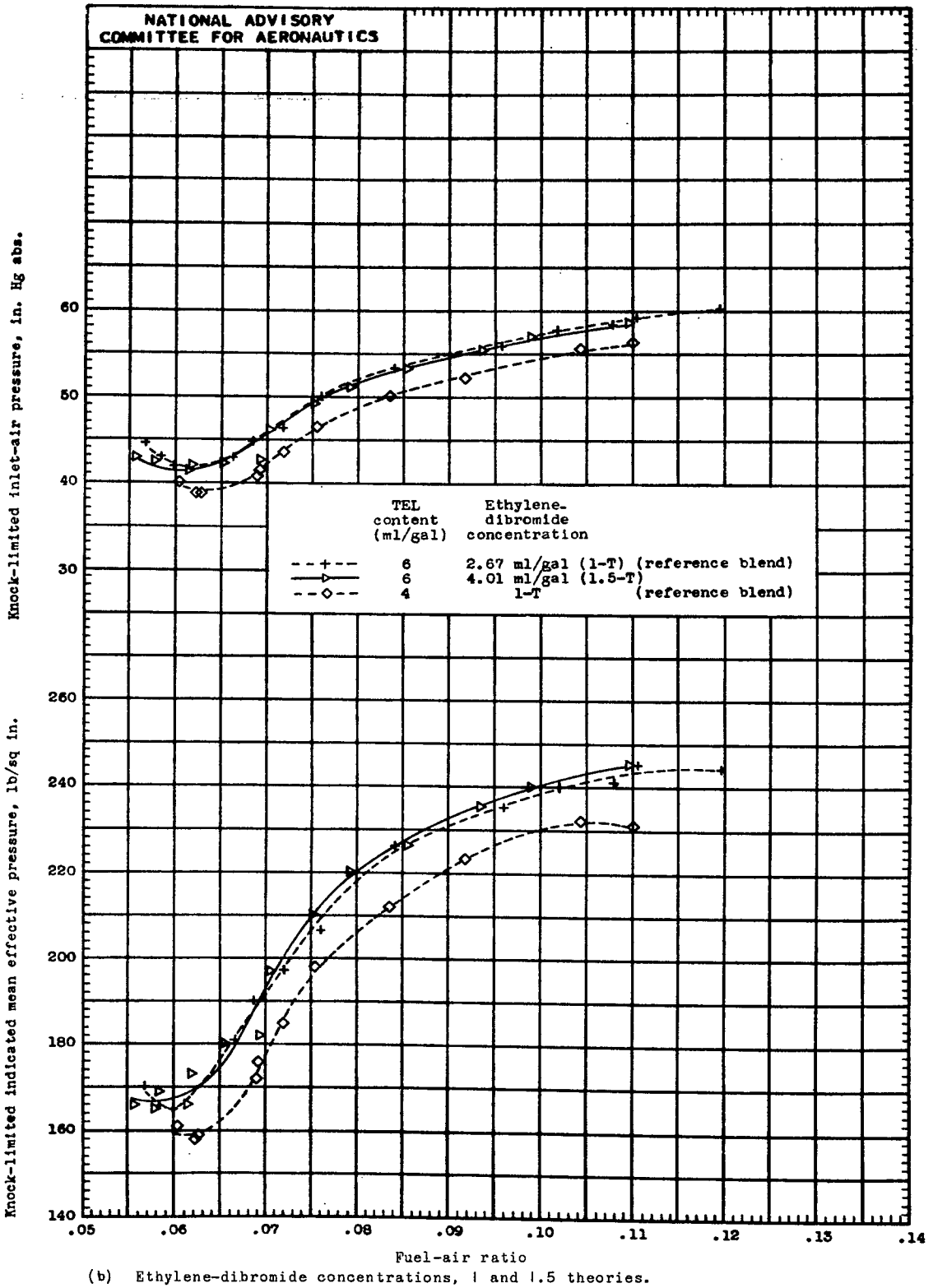


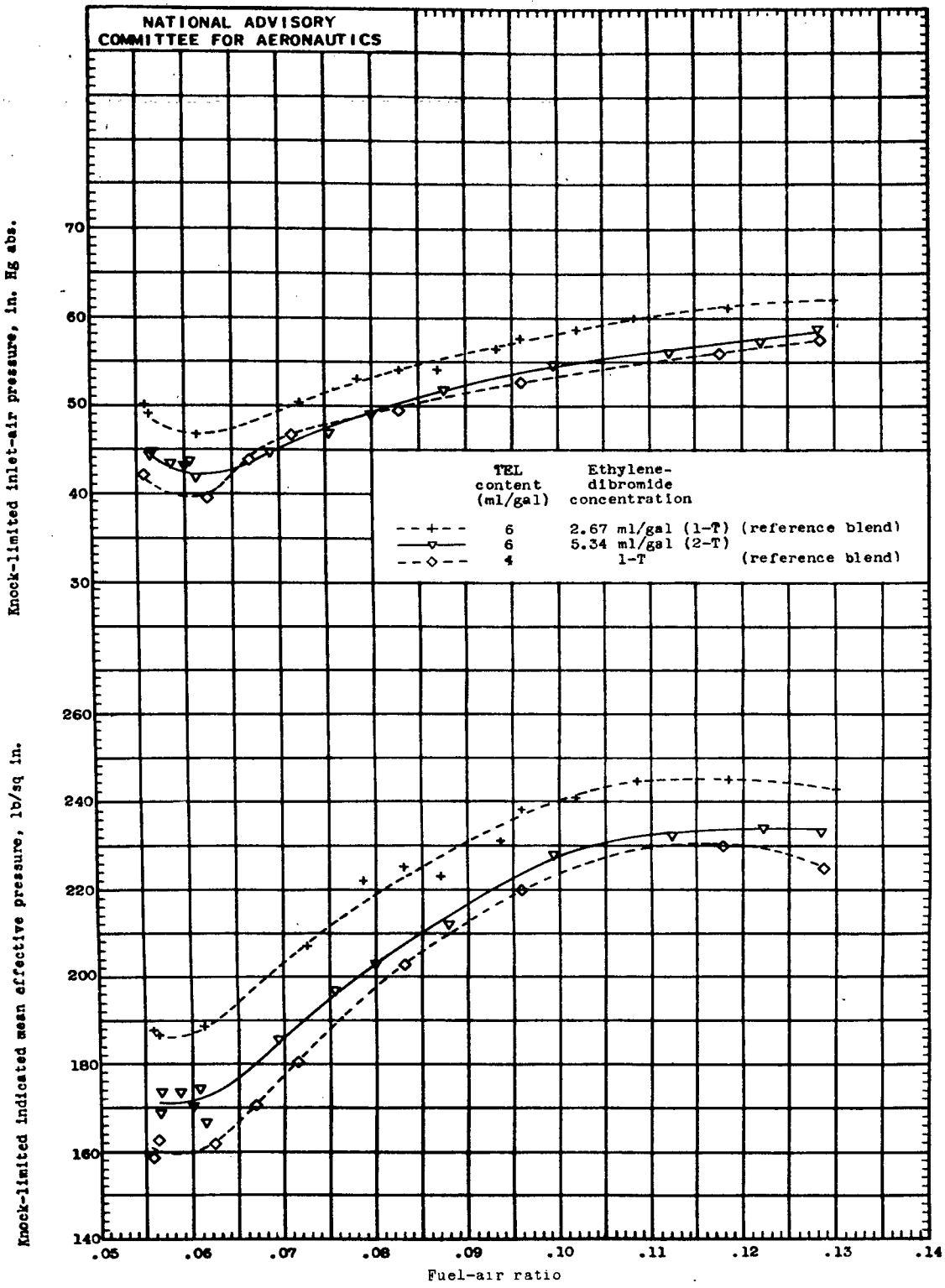
(a) Ethylene-dibromide concentrations, 0 and 1 theories.

Figure 1. - Effect of ethylene dibromide in S reference fuel leaded to 6 ml TEL per gallon on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; spark advance, 45° B.T.C.; coolant temperature, 375° F; inlet-air temperature, 225° F.



(b) Ethylene-dibromide concentrations, 1 and 1.5 theories.

Figure 1. - Continued. Effect of ethylene dibromide in S reference fuel leaded to 6 ml TEL per gallon on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; spark advance, 45° B.T.C.; coolant temperature, 375° F: inlet-air temperature, 225° F.



(c) Ethylene-dibromide concentrations, 1 and 2 theories.

Figure 1. - Concluded. Effect of ethylene dibromide in S reference fuel leaded to 6 ml TEL per gallon on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; spark advance, 45° B.T.C.; coolant temperature, 375° F; inlet-air temperature, 225° F.

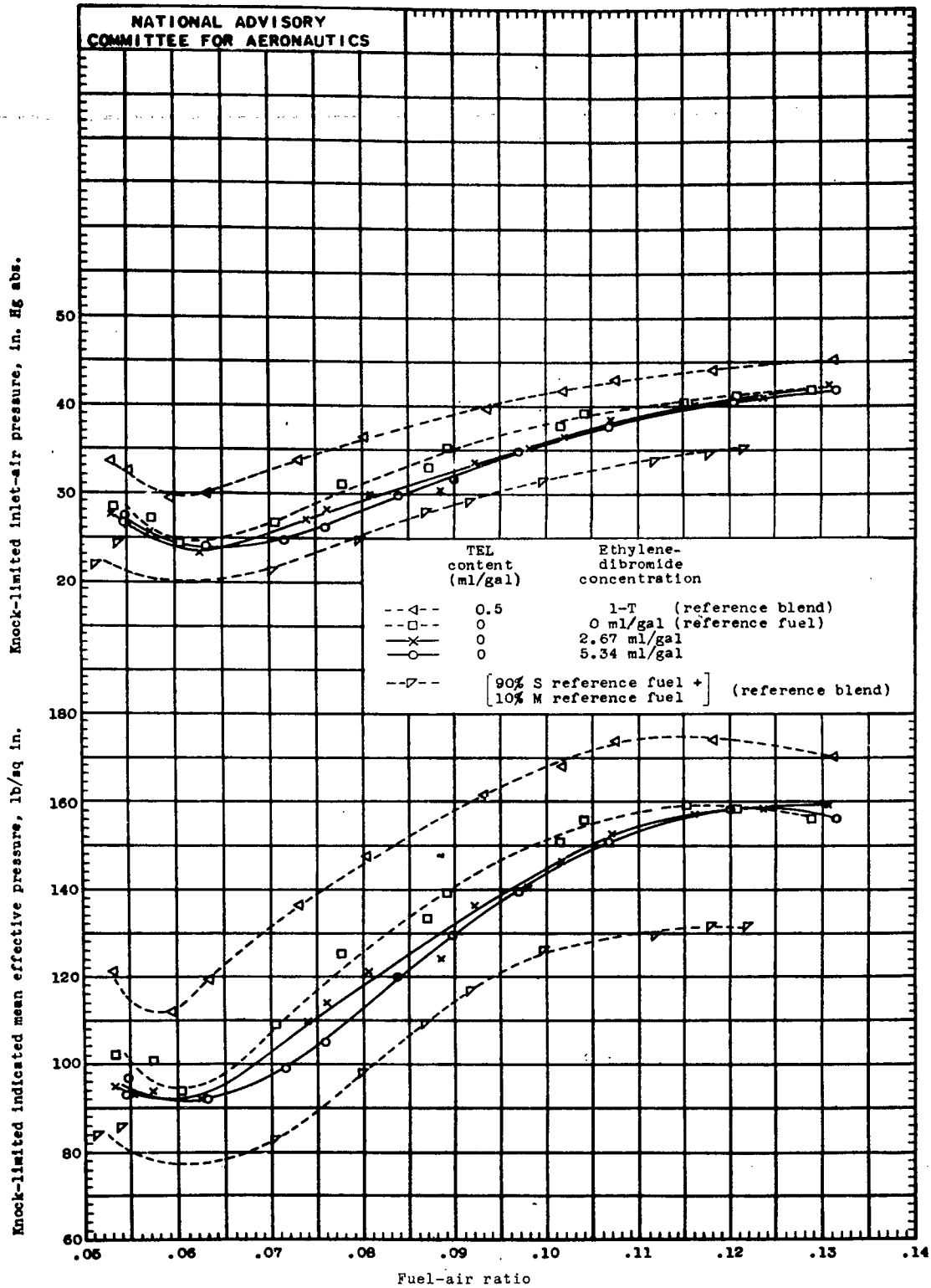


Figure 2. - Effect of ethylene dibromide in nonleaded S reference fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; spark advance, 45° B.T.C.; coolant temperature, 375° F; inlet-air temperature, 225° F.

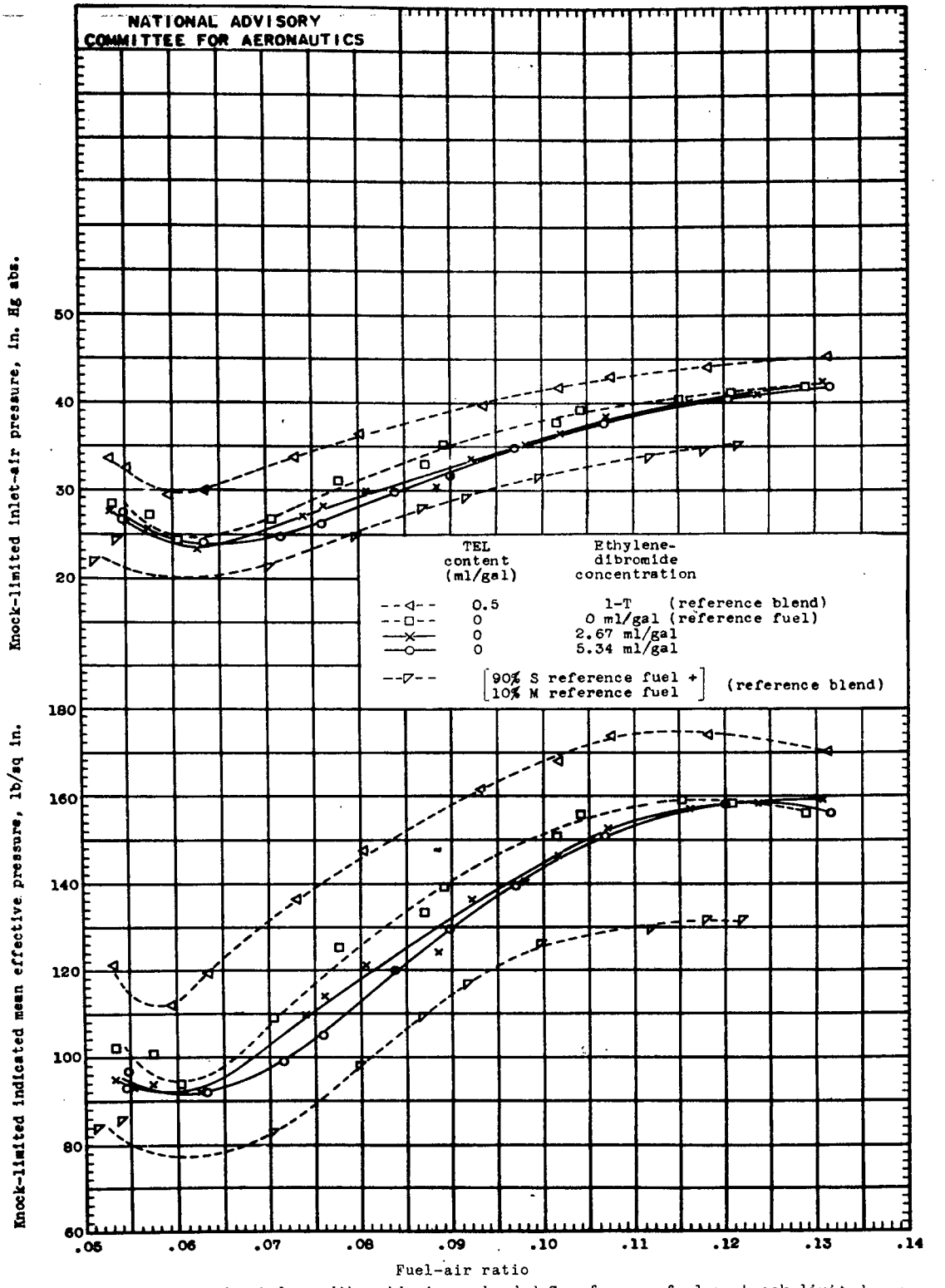


Figure 2. - Effect of ethylene dibromide in nonleaded S reference fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; spark advance, 45° B.T.C.; coolant temperature, 375° F; inlet-air temperature, 225° F.

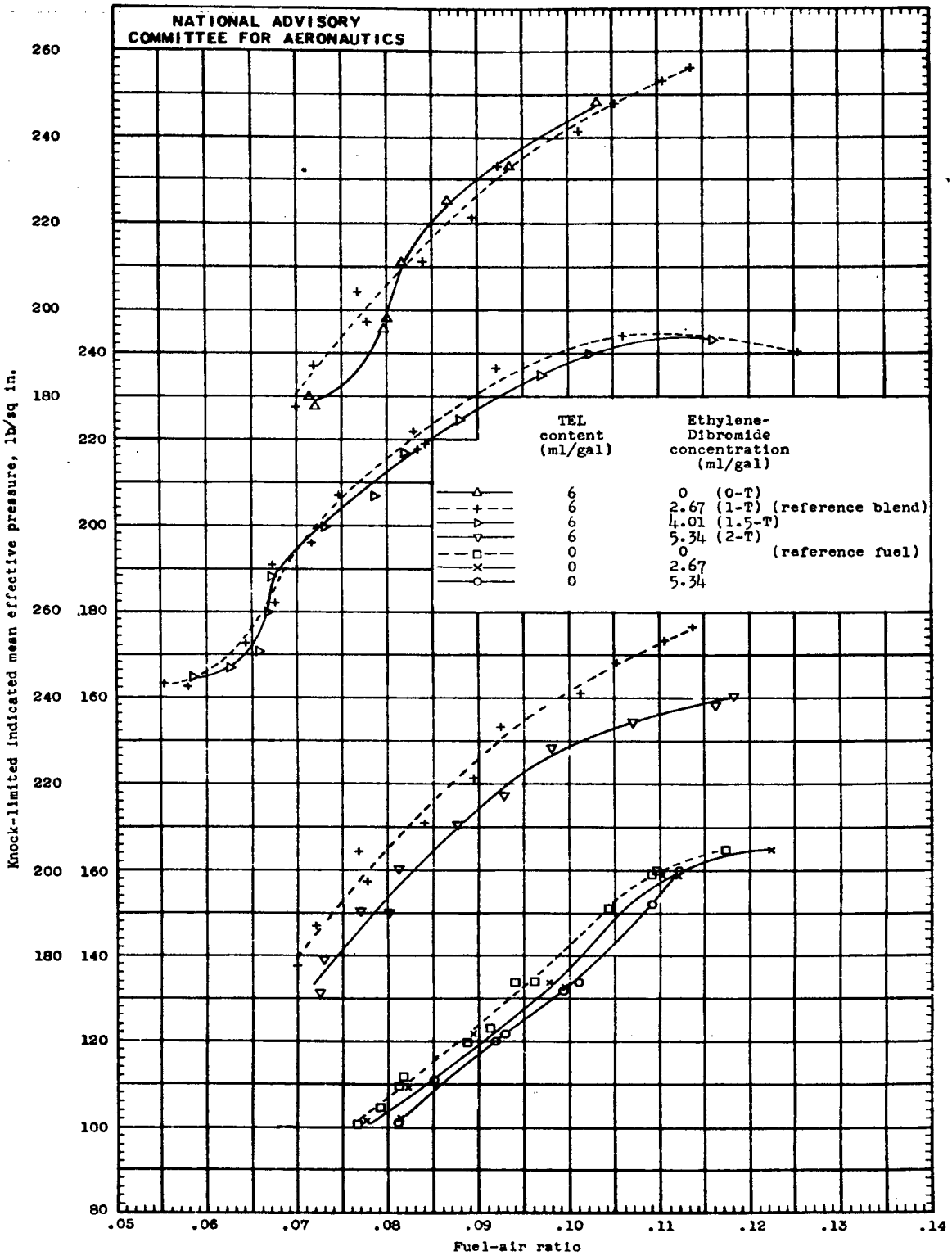


Figure 3. - Check curves for data presented in figures 1 and 2.